An Evaporation Model of Wing Tank Fuel Flammability

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Motivation

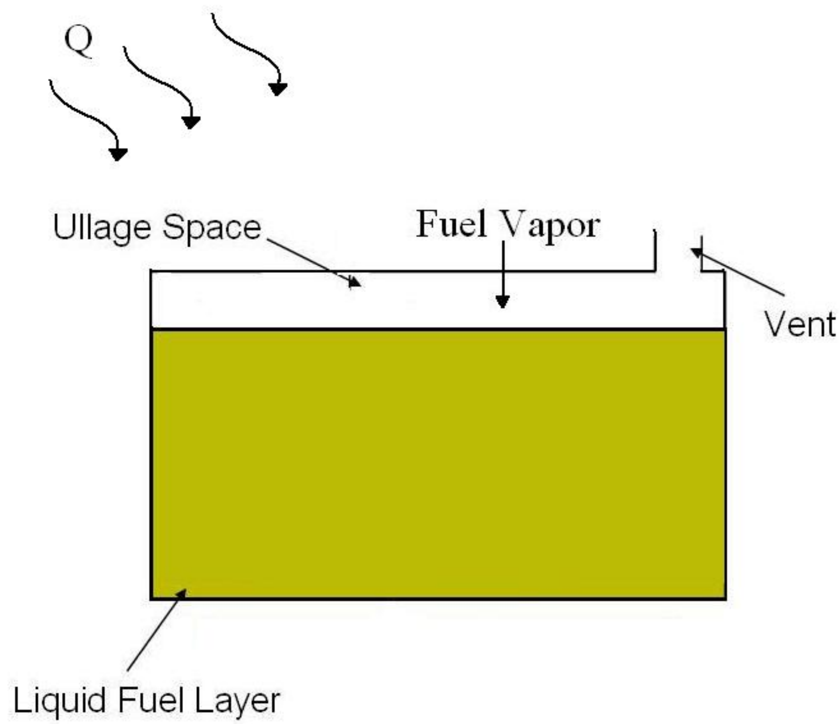
- Numerous accounts of wing tank explosions across the world
- Current regulation is based on unheated aluminum wing tanks
- Different boundary conditions present in WTs and CWTs.
- Study of flammability in WTs will help change the baseline of flammability in fuel tanks.

Overview

- Center Wing Tank (CWT) Flammability Model
- Flight Test Data
- Wing Tank Flammability Model
- Comparison with Altitude Chamber and Wind Tunnel Test Data
- Conclusions

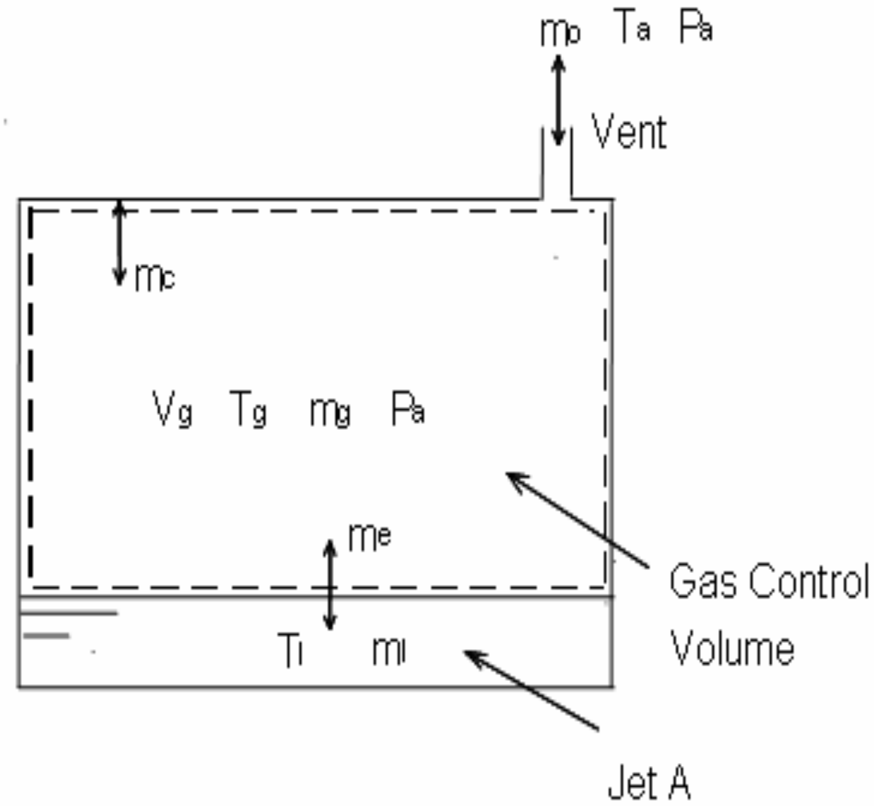
Problem Description

- Study the generation of flammable vapors in the ullage of a wing fuel tank that is
  - Radiatively heated the top surface
  - High mass loading
    > 60% fuel



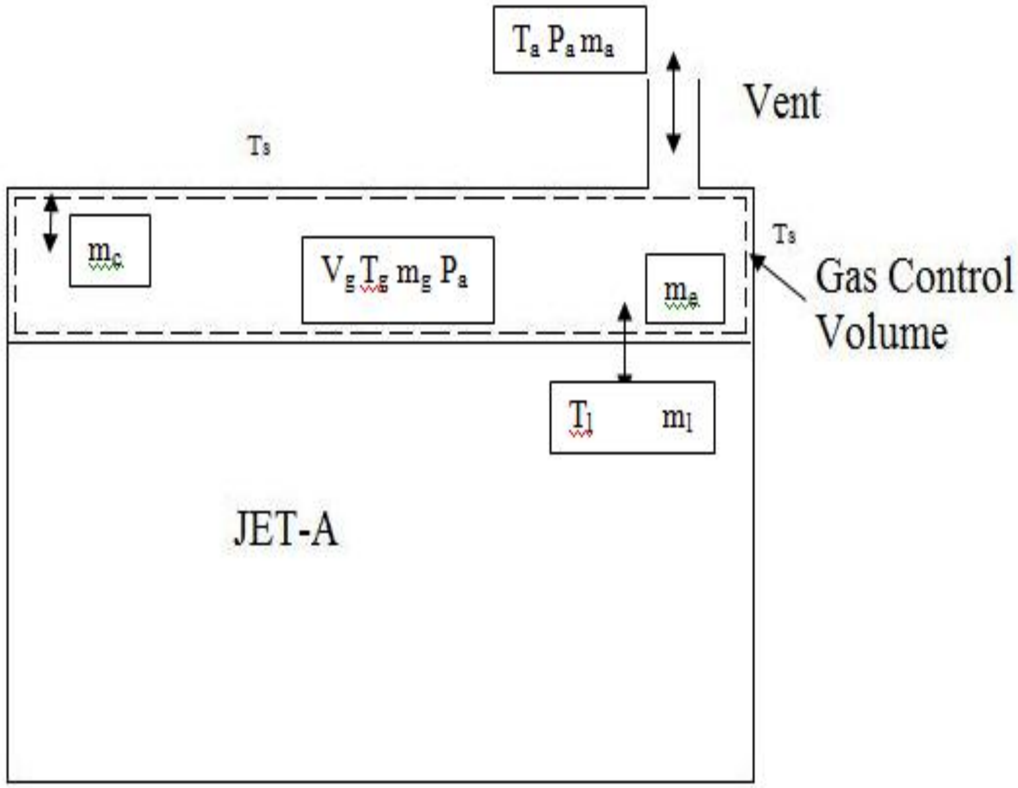
Center Wing Tank Model (Polymeropoulos, 2001)

- Convective heat and mass transfer
  - Liquid vaporization
  - Vapor condensation
- Variable ambient pressure and temperature
- Vented Tank
- Multi-component fuel
- Initial temperature of the system is constant



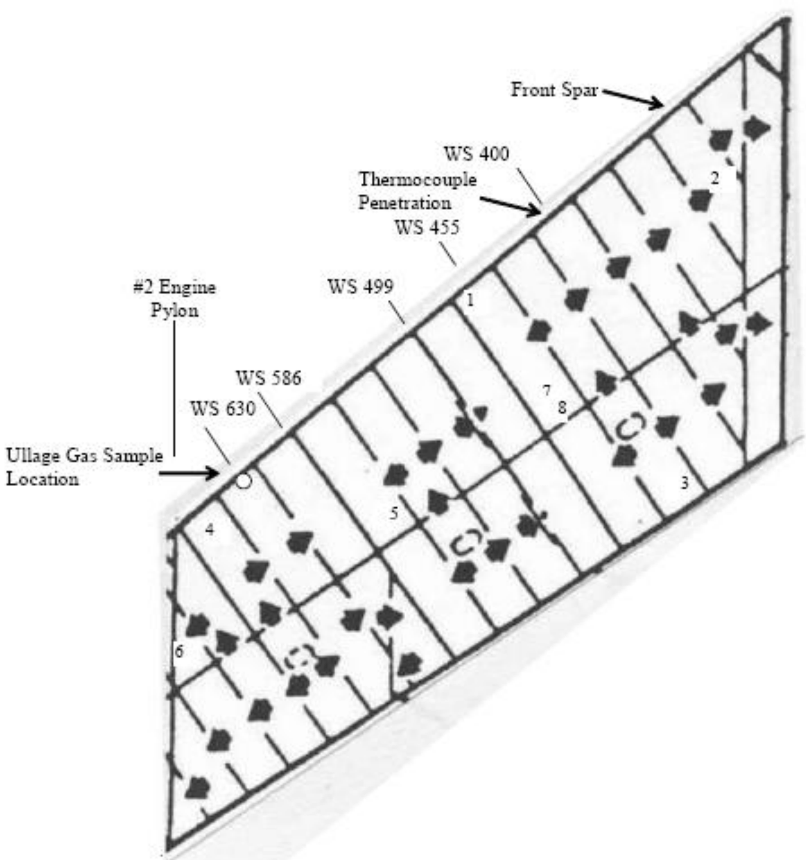
Wing Tank Variation

- Higher mass loading
  - Fuel is larger fraction of surface area
- Heated from above
  - Inhibited mixing due to stable density field



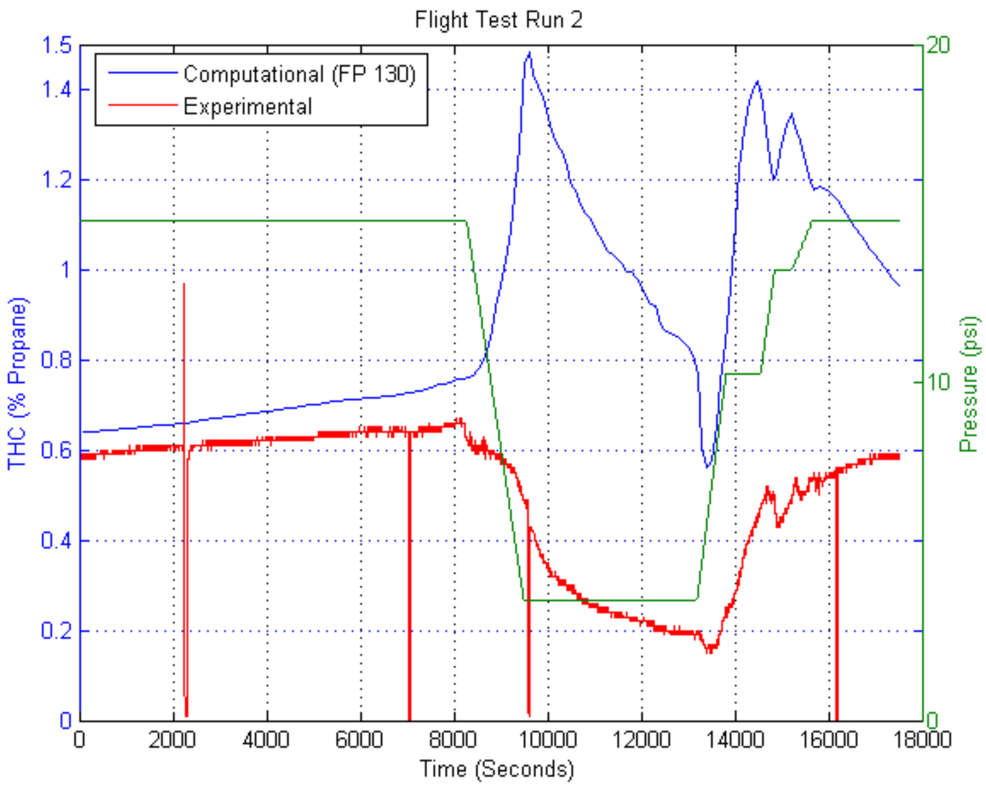
Flight Tests – Does the CWT model work for the WT?

Flight Test Experimental Setup



- NASA 747 SCA wing tank
  - Instrumented with
    - Thermocouples
    - NDIR THC Analyzer

Flight Test Results



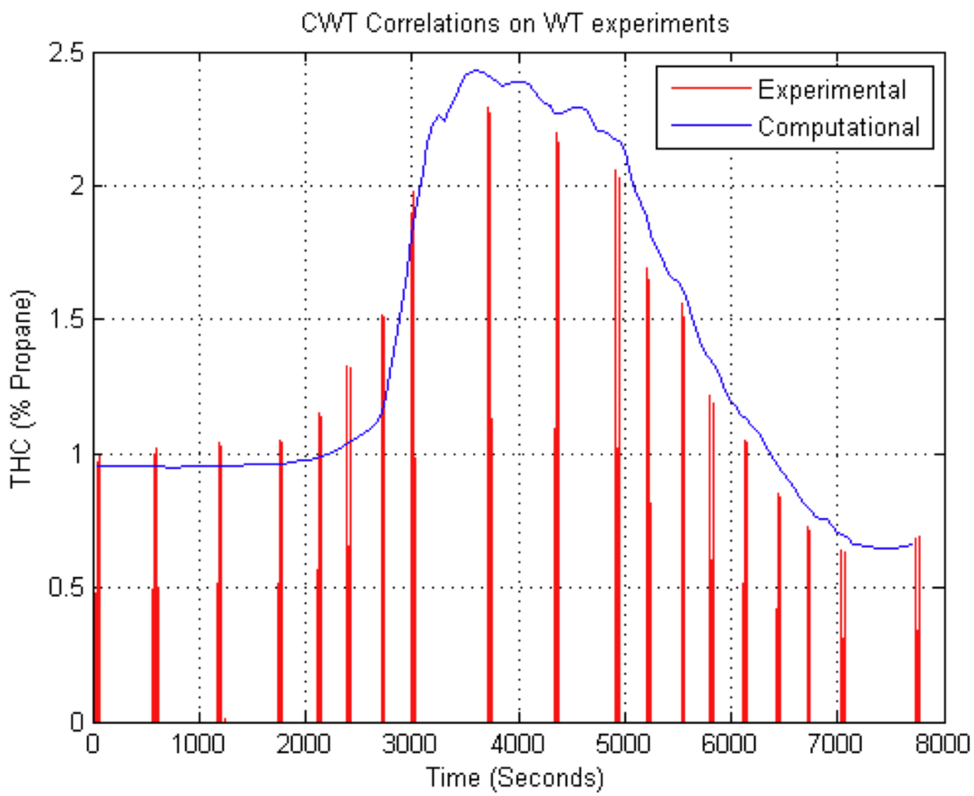
- Assumptions
  - Rectangular geometry
  - Mass Loading: 60%
  - Computational model is CWT
  - Experimental Data is WT

Go to simplified wing tank geometry to see why CWT model fails

Altitude Chamber Testing – Rectangular Wing Tank Simulation Test Bed

Instrumented with hydrocarbon gas analyzer and multiple thermocouples

Comparison of CWT Modeling with Experiment

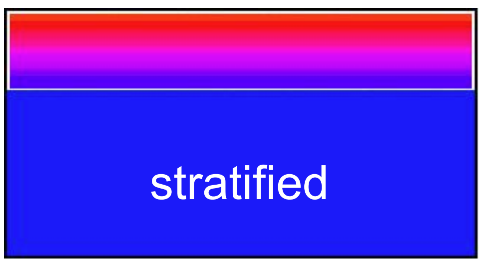


CWT Model misses dynamics of hydrocarbon evolution

Create an updated physical model

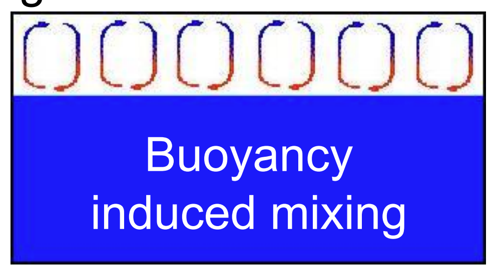
- Reduced wetted surface area
  - Less condensation/evaporation from non-immersed surfaces
  - Less dependence on hot/cold spots
- Higher mass loading
  - Large thermal mass of fuel
- Stratification (?)

Heated from above



Stable density layers

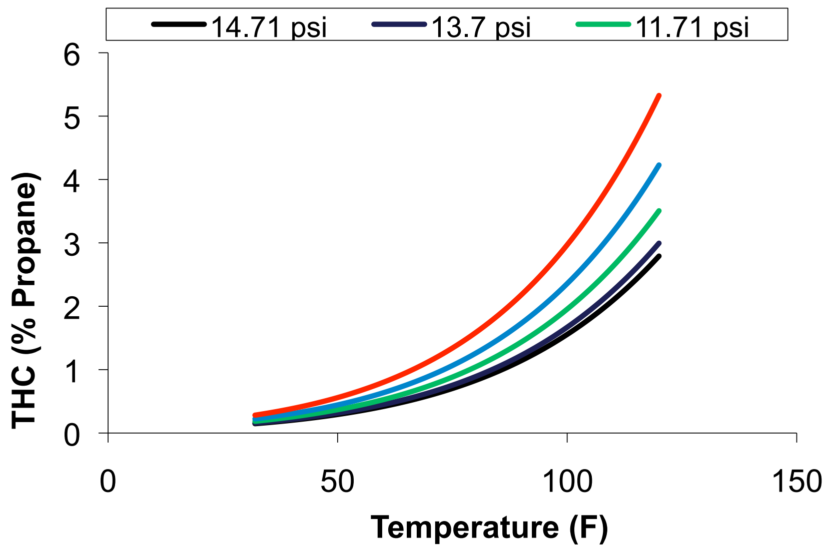
Rayleigh-Benard convection cells

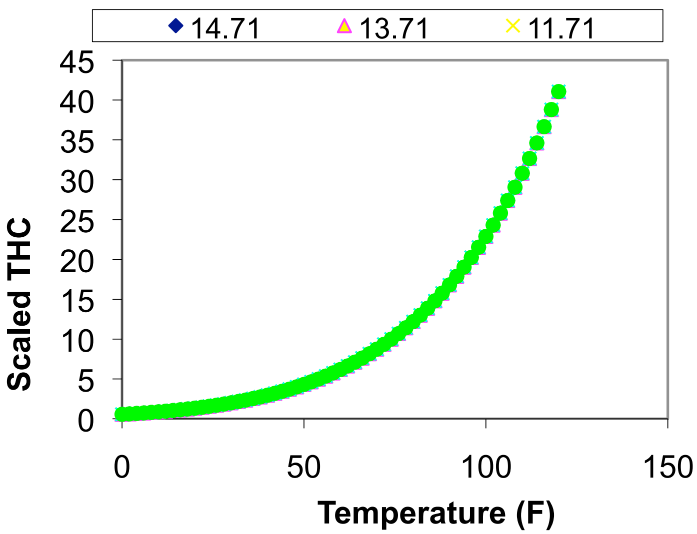


Heated from below

- Strong correlation between instantaneous ullage temperature and THC

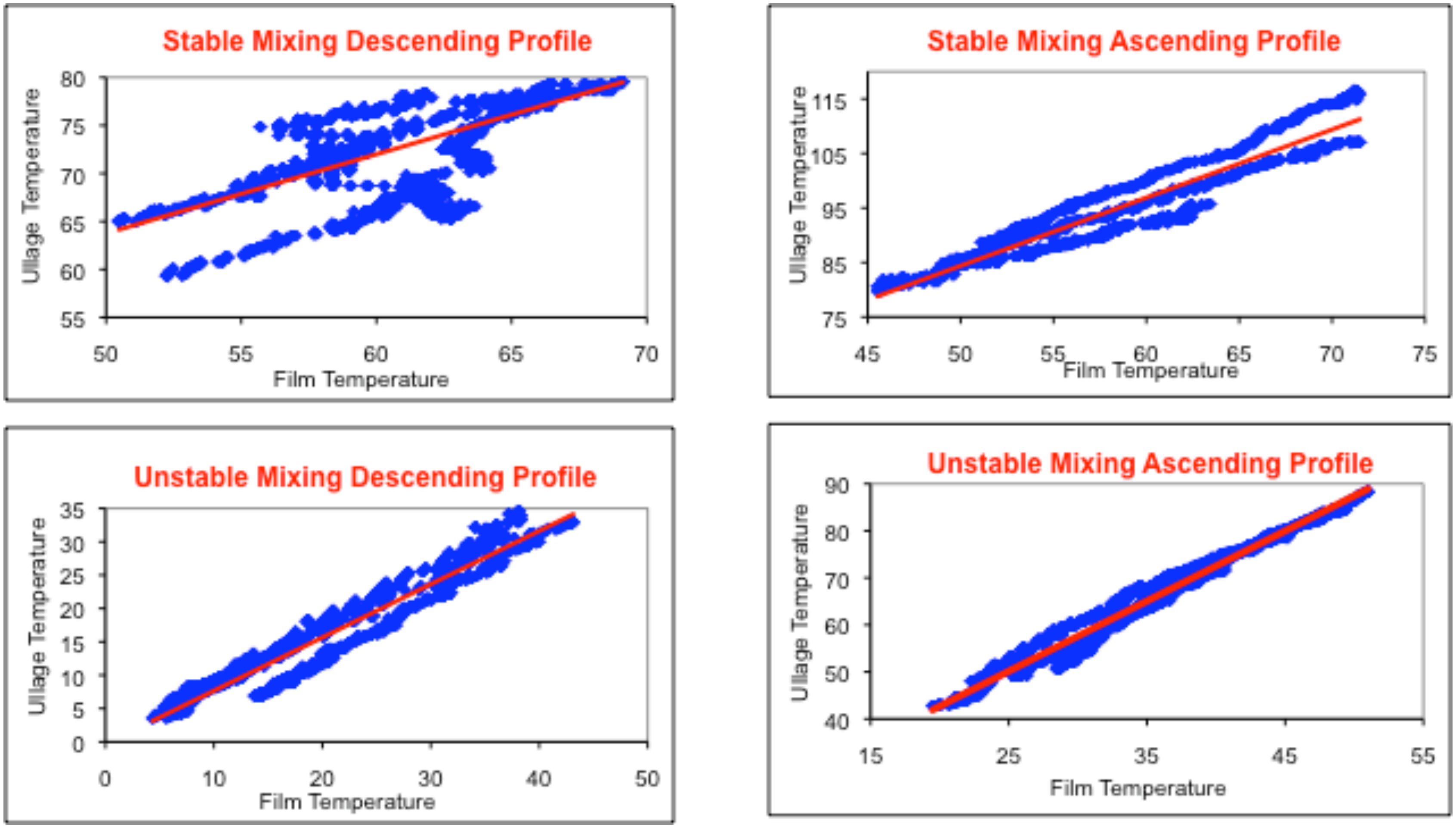
Correlation of THC with "Film" Temperature





- Model uses FAR calculator created by Ivor Thomas
- Fuel to Air ratios are calculated at constant pressure over a range of temperatures.
- Collapse onto a single curve with simple pressure scaling
- Used to approximate liquid surface temperature associated with mass transport

Correlation between Ullage Temperature with Film Temperature – Flight Test Data

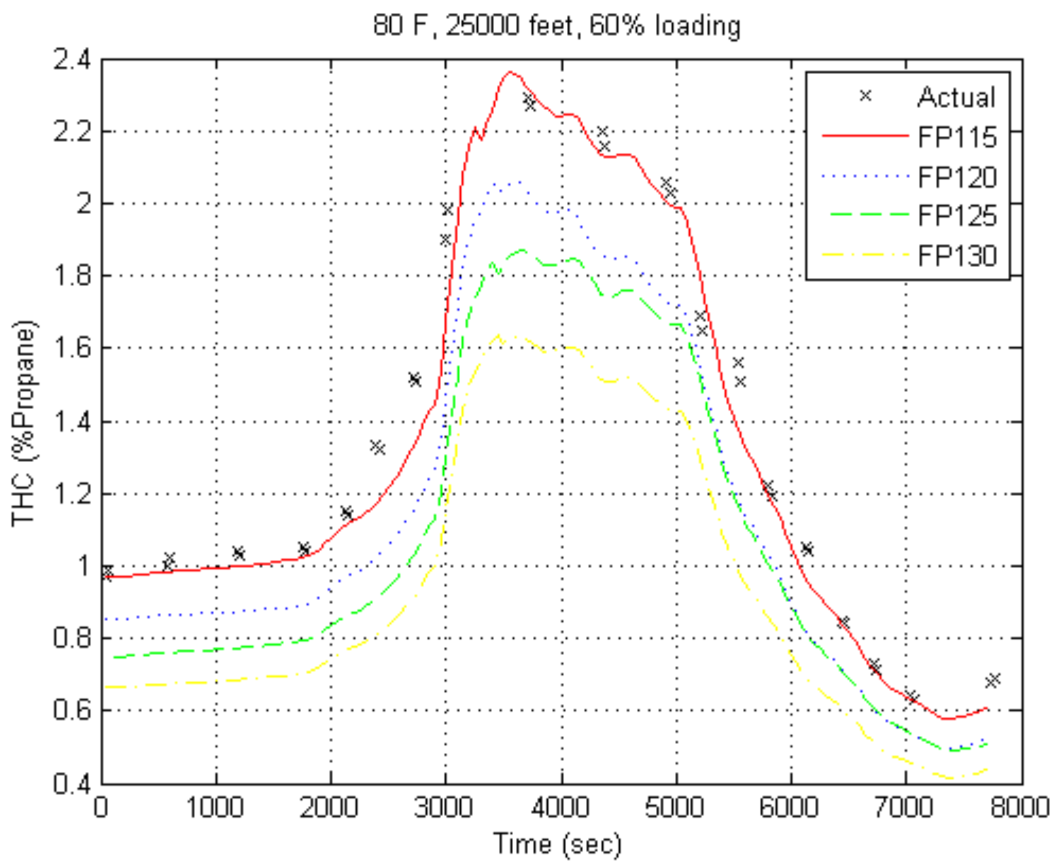


Film temperature calculated using measured THC and FAR correlation shown earlier

Altitude Chamber Tests

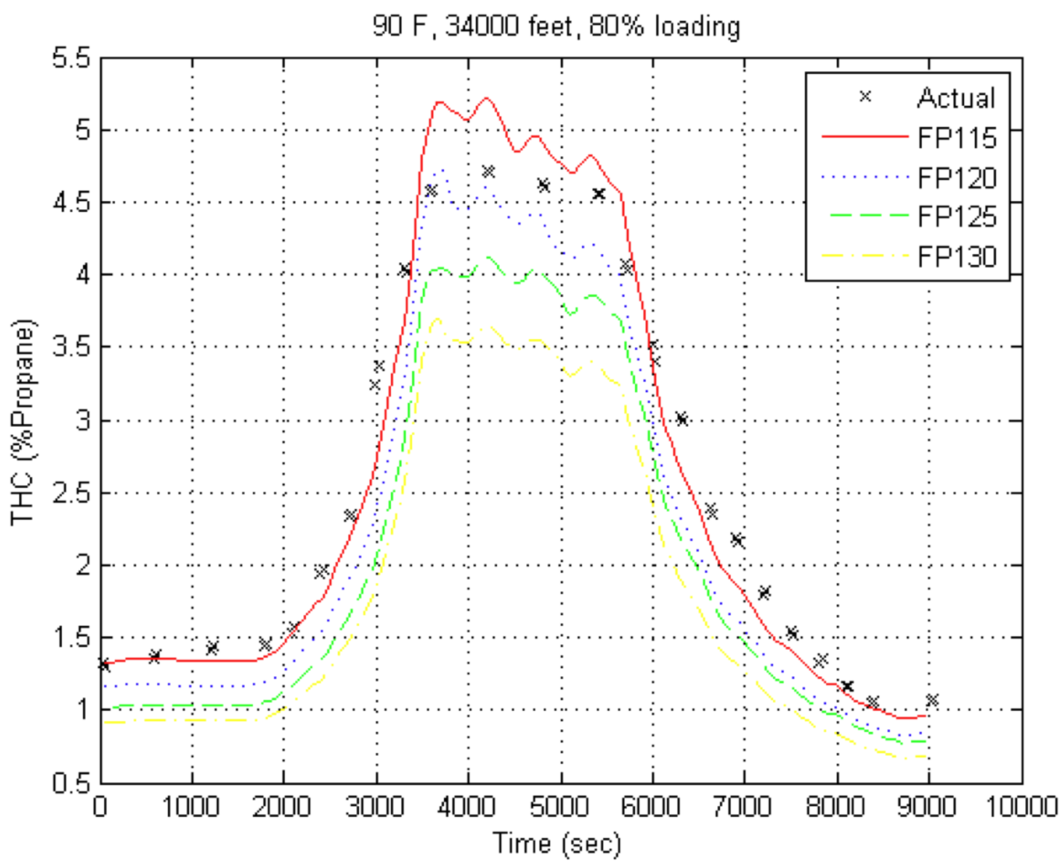
	60% Mass Loading		80% Mass Loading	
	Cruising Altitude		Cruising Altitude	
Temperature	25000 feet	34000 feet	25000 feet	34000 feet
80°F	X	X	X	X
90°F	X	X	X	X
100°F	X	X		

Altitude Chamber Results



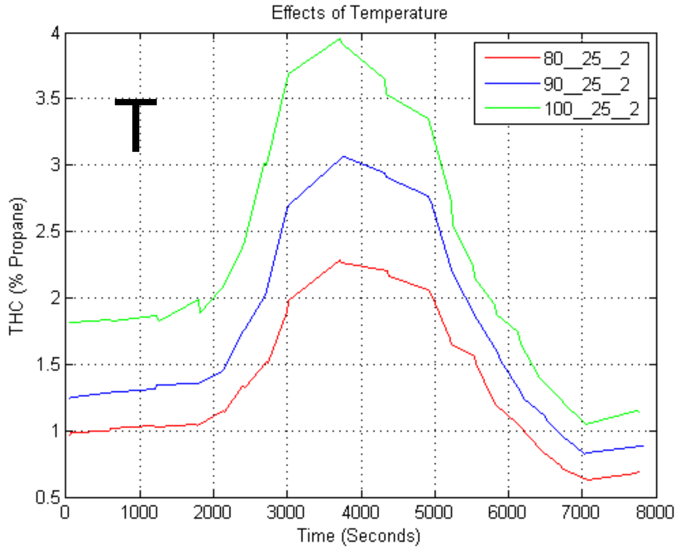
- Test Conditions
  - Initial Temp: 80°F
  - Cruising Alt: 25,000 feet
  - Mass Loading: 60%

Altitude Chamber Results

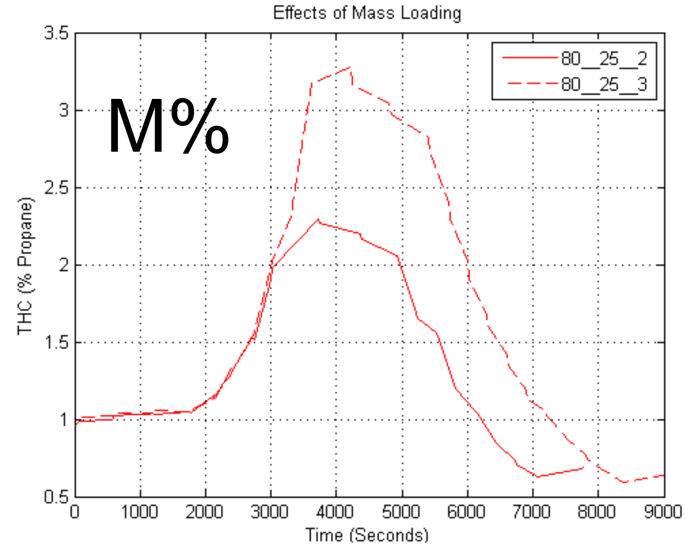


- Test Conditions
  - Initial Temp: 100°F
  - Cruising Alt: 34,000 feet
  - Mass Loading: 80%

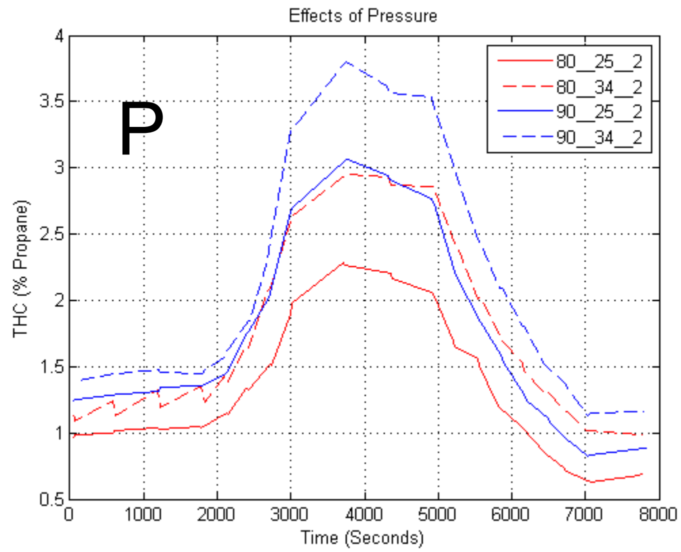
Thermodynamic scaling



Maximum THC scales with initial temperature

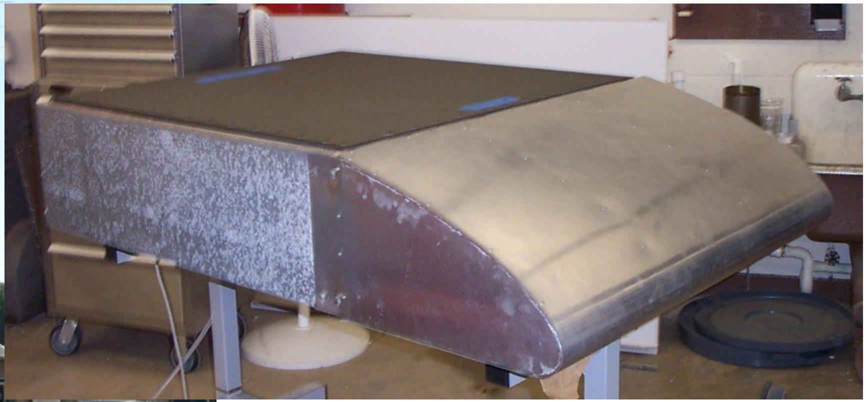


THC increases with larger mass loading



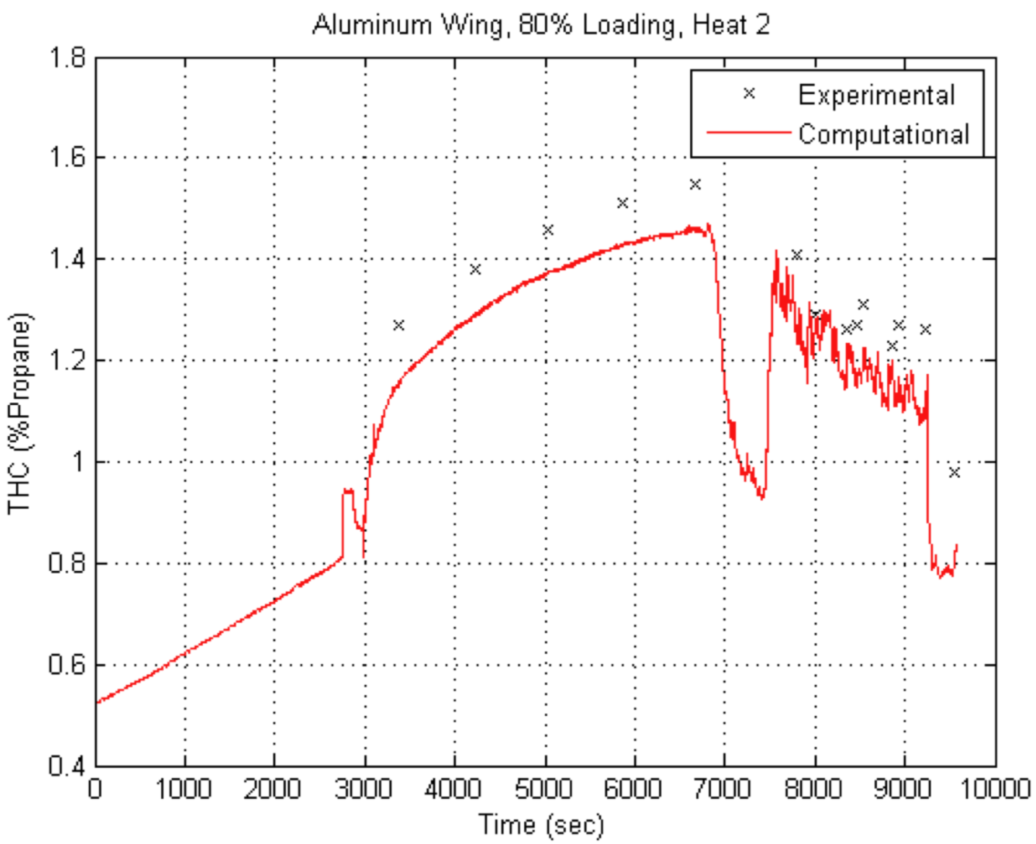
THC increases with decreasing altitude

Wind Tunnel Testing



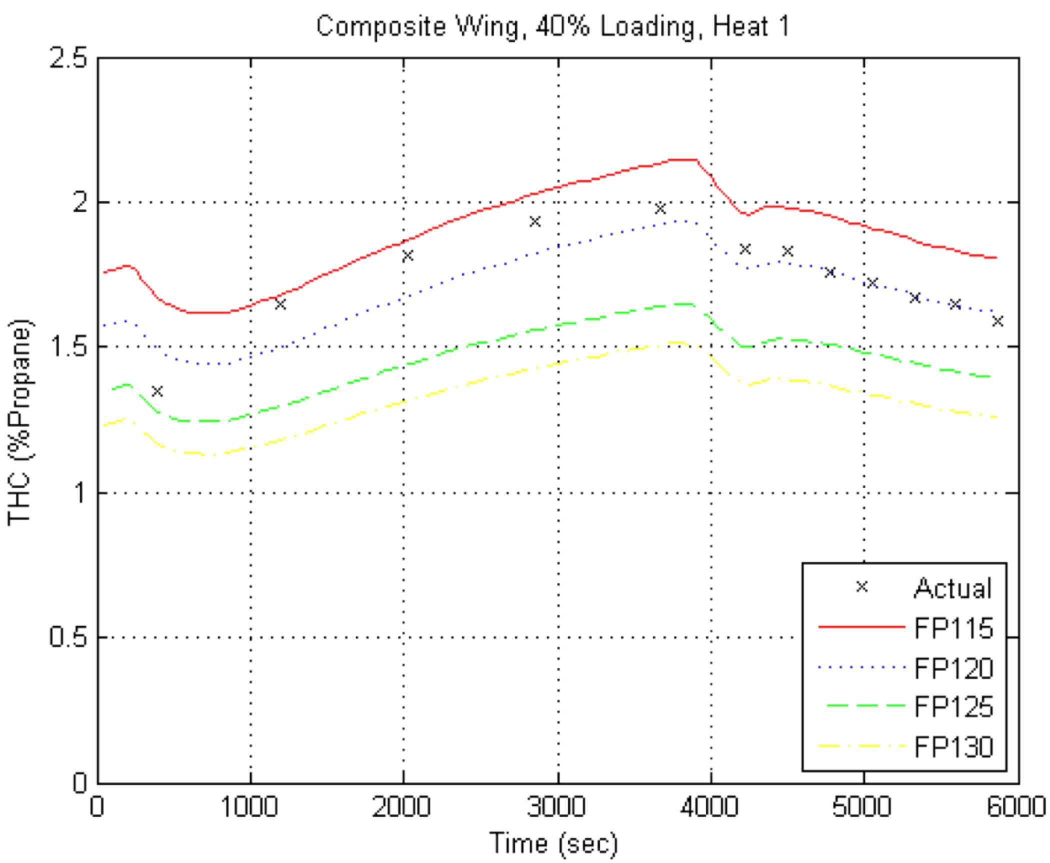
Wing tank simulator installed in air induction facility high speed test section

Wind Tunnel Results



- Test Conditions
  - Aluminum wing tank
  - Mass Loading: 80%
  - High radiant Heat Setting

Wind Tunnel Results



- Test Conditions
  - Carbon fiber composite wing tank
  - Mass Loading: 40%
  - Low radiant Heat Setting

Conclusions

- CWT Model shows some difficulty with wing tank geometries and high mass loading.
- Algebraic model for wing tank flammability was developed.
- Model was able to accurately predict THC values in altitude chamber, wind tunnel, and actual flight tests using only local thermodynamic data (T and P at fuel surface).
- Computational results correlated best with experimental results at a lower flash point (FP ~ 115 °F).
- Loaded Wing Tank mass transport dominated by fuel surface temperature unlike CWT.